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TITLE OF THE INVENTION

ANTENNA FOR TRANSPONDER AND TRANSPONDER

FIELD OF THE INVENTION

a The present invention relates to ~~antennas for transponders and to~~ transponders and antennas for use therewith. In

a particular, the present invention relates to an antenna ~~an antenna for a transponder~~ and a transponder operating at a frequency of 40 kHz to 200 kHz, or at a frequency exceeding 100 kHz, which is suitable for the usage of an apparatus carried on a person, such as an ID card, a commuter pass and a coupon ticket.

DESCRIPTION OF THE RELATED ART

a Antennas which have previously been used in the prior art include those ~~of a winding~~ on a ferrite magnetic core, and those of a wound conductor without a magnetic core. In antennas used in

a ~~alternate~~ alternating magnetic fields, the use of the magnetic core comprising layered thin plates prevents

a ~~a loss due to~~ losses resulting from eddy ~~current~~ currents.

When a prior art antenna is used for transponders carried on persons for ID cards,

a commuter passes and coupon tickets, the following problems arise:

a Because ferrite is hard and unflexible ~~, not flexible, and thus fragile against bending,~~ it is not suitable

a for being carried in a jacket, shirt or pants pocket.

Although a coil not having a magnetic core can be made thin by forming a concentric

a spiral coil 1 as shown in FIG. 2A, the coil characteristics are lowered when a coin 10 or ~~the~~ aluminum foil in a cigarette case in a person's pocket overlaps perpendicularly with the axis of

a transponder 2 having such a coil 1, as shown in FIG. 2B. Such a characteristic deterioration can be prevented with significant inconvenience by taking the transponder out of the pocket when using it. Further, such a use may cause the deterioration of characteristics due to attached water drops or snow.

When a metallic magnetic core is used with an ~~alternate~~ alternating current, ~~the loss due to~~ losses resulting from eddy ~~current has~~ currents have been prevented by layering thin magnetic plates having high electric resistance while insulating the plates from ~~each other~~ one another. Such an effect is more greatly enhanced with a higher electric resistance and a smaller thickness of the magnetic material. However, at a frequency exceeding a few dozen kHz, and in particular, a few hundred kHz, a significant loss is ~~caused~~ produced and thus it is not suitable for use even if a material is used which has the highest electric resistance and the smallest thickness and is industrially available, i.e., an amorphous metal having an electric resistance of 137 $\mu\Omega$cm and a thickness of 23 μ.

~~OBJECT~~ SUMMARY OF THE INVENTION

It is an object of the present invention to provide ~~an antenna for~~ a transponder and a ~~transponder using thereof~~ antenna, which is thin and flexible, has ~~a small~~ low loss at ~~a~~ high frequency, and is ~~barely~~ insignificantly affected by a coin or ~~an~~ aluminum foil such as that used for cigarette packaging.

An antenna for a transponder in accordance with a first embodiment of the present invention comprises a magnetic core composed of layered rectangular metallic thin plates, and a coil wound parallel to ~~the longer side~~ a greater dimension of the magnetic core.

Because the magnetic core in such an antenna for a transponder is composed of layered metallic thin plates, the antenna is thin and flexible, and has a decreased high-frequency loss.

By winding a coil ~~the longer side direction~~ parallel with a longer dimension of the magnetic core, the loss is significantly decreased at a high frequency region over a few dozen kHz.

When the antenna for the transponder is mounted in a transponder, the magnetic flux flows parallel to the transponder's plane. Thus, the magnetic flux is barely affected by a coin or aluminum foil overlapped on the transponder's plane.

A transponder in accordance with a second embodiment of the present invention has two plate antennas each comprising a magnetic core composed of layered metallic thin plates wound with a conductor coil, and an air-core antenna composed of a spirally wound conductor.

An antenna for a transponder in accordance with a third embodiment of the present invention comprises a plate magnetic core composed of a composite material of a soft magnetic flake and a synthetic resin, and a coil wound on such a magnetic core.

Such an antenna for a transponder is thin and flexible and has a decreased high-frequency loss, because the magnetic core is composed of a composite material ~~of~~ such as a soft magnetic flake and a synthetic resin.

When the antenna for the transponder is fabricated in a transponder, the magnetic flux flows parallel to the transponder plate. Thus, the magnetic flux is barely affected by a coin or aluminum foil overlapped on the transponder plate.

A transponder in accordance with a fourth embodiment of the present invention comprises two plate antennas in accordance with the third embodiment set forth above, and an air-core antenna composed of a spirally wound conductor.

BRIEF DESCRIPTION OF THE DRAWINGS

a FIG. 1 is an isometric view illustrating ~~an~~ a first antenna in accordance with an embodiment of the present invention;

FIG. 2A is a plan view illustrating a transponder having a prior art antenna and FIG. 2B is an isometric view of the same;

FIGs. 3A and 3B are plan views illustrating a magnetic core in accordance with an embodiment of the present invention;

FIG. 4A is a plan view illustrating a transponder in accordance with an embodiment of the present invention and FIG. 4B is an isometric view of the same;

FIG. 5A is a plan view illustrating a transponder also usable as a magnetic card and FIG. 5B is a side view of the same;

FIGs. 6A and 6B are representative views illustrating the length, width and thickness of coils in Example (6A) and Comparative Example (6B); and

FIG. 7A is a plan view illustrating a transponder in accordance with an embodiment of the present invention, and FIG. 7B is a side view of the same.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

a A ~~An antenna for a~~ transponder antenna in accordance with a first embodiment of the present invention will now be explained.

FIG. 1 is an isometric view illustrating a preferable feature of an antenna in accordance with the first embodiment of the present invention.

This antenna comprises a magnetic core 4 composed of layered metallic thin plates, and

a coil 5 wound thereon.

Preferred materials for the metallic thin plate are soft magnetic materials, and in particular, of having excellent magnetic properties and a large specific resistance. Examples of such materials include amorphous magnetic materials, such as METAGLAS 2714A (Co-Fe-Ni-B-Si type), 2605S2 (Fe-B-Si type), 2605SC (Fe-B-Si-C type) and 2876MB (Fe-Ni-Mo-B type) made by Allied Signal; iron-nickel alloys, such as JIS 2531 PB PC; silicon steels, such as JIS 2553 Z6H and RC6HL GO9 SO9; and the like. Among them, Co-Fe-Ni-B-Si-type amorphous magnetic material is more preferred, and the preferable thickness of ~~the~~ each metallic thin plate ranges 20 to 50 μm.

The number of the layered metallic thin plates is preferably 3 to 16. Although only metallic thin plates can be layered without inserting other material, metallic thin plates which are insulated by coating or oxidizing the surface of the plate also may be layered. Further, in order to secure the insulation between the metallic thin plates, an insulating material, such as paper and polymeric films may be inserted between the metallic thin plates in the layering.

The ratio B/A of the shorter side length B to the longer side length A in the magnetic core 4 composed of layered metallic thin plate is 1 or less, preferably 0.4 to 1.0 and more preferably 0.5 to 0.9.

The conductor wound up as the coil 5 is preferably 100 to 200 μm in diameter. When the coil 5 is formed, the conductor is wound up in the direction parallel to a greater dimension ~~the long side~~ of the magnetic core 4. The preferable thickness of the antenna 3 after the coil is wound up is 0.4 mm or less, and ~~more~~ preferably 0.3 mm or less.

The cross-section of the conductor for the coil is typically circular, and is preferably

rectangular for the compact coil. The materials for the conductor are pure copper for general use, chromium copper (copper-base alloy containing chromium) for use requiring the strength due to vibration, highly conductive silver for compact size, corrosion resistive gold for use requiring high reliability, and aluminum for light weight.

The magnetic core of the antenna in accordance with the present invention is flexible in order to prevent breakage due to bending. Further, because the antenna is thin and the coil axis can be set to be parallel to the transponder plate, its characteristics are barely lowered when a coin or aluminum foil overlaps with the transponder. Thus, the antenna has a small loss at a high frequency.

a In particular, when the corners of the magnetic core are reduced to form oblique angles ~~cut~~ or rounded as shown in FIGS. 3A and 3B and in Examples described after, the loss can be further suppressed at a high frequency. The loss in the antenna in accordance with the present invention, of which the coil is wound up with the magnetic core composed of layered metallic thin plates parallel to a greater dimension ~~in the longer side~~ direction, is significantly lowered at a high frequency region of a few dozen kHz, and the most of the loss is generated at the corners of the magnetic core. Thus, the corners are reduced to form oblique angles ~~cut~~ or rounded like a magnetic core 3A shown in FIG. 3A or core 3B shown in FIG. 3B, respectively, to decrease the loss.

a When the corners are reduced to form oblique angles ~~cut~~, the length of the cut side (a in FIG. 3A) is generally 2 to 12 mm, preferably 3 to 10 mm, and more preferably 4 to 8 mm. When the corners are rounded, the curvature radius R is generally 2 to 15 mm, preferably 3 to 12 mm, and more preferably 4 to 10 mm.

a Next, a transponder ~~of~~ and antenna according to a second embodiment of ~~using the antenna in accordance with~~ the

present invention will be explained.

The transponder in accordance with the present invention is produced by embedding the antenna 3 for the transponder, as well as a circuit chip, into a synthetic resin. The preferred size of the transponder is 54 mm in width and 86 mm in length, similar to credit cards generally used. A size ~~larger~~ greater than this is too bulky to carry, whereas a size less than this may often be lost, both resulting in inconvenient handling. The preferred thickness of the transponder is 0.76 mm or less, similar to credit cards.

As shown in FIGS. 4A and 4B, the plate transponder 8 in accordance with the present invention is provided with two thin plate antennas 6, 7, while their coil axes (or antenna axes) are perpendicular to ~~each other~~ one another, and an air-core antenna composed of an air-core spiral coil 9 is provided in the transponder 8, so that the axis is perpendicular to the transponder plate. Axes of the antennas 6, 7 and of the antenna composed of the coil 9 are preferably directed in three directions perpendicular to each

other. These antennas have chip circuits 11.

When the transponder is used as an ID card or a commuter pass for an automated wicket in a pocket, the transponder must respond to radio waves from any ~~directions~~ direction, because the correlation of the directions between the antenna of the interrogator and the transponder is not defined. Although the plate transponder can respond to all the directions parallel to the plate by providing two plate antennas which cross their axes, such a transponder cannot respond to the plane perpendicular to the plate. Further, the spiral antenna cannot respond to the direction parallel to the plate. On the other hand, the plate transponder shown in FIGs. 4A and 4B can respond to radio waves from all the directions, regardless of the direction of the transponder;

the antenna 7 responds to radio waves in the X direction, the antenna 6 responds to radio waves a in the Y direction, and the air-core antenna (coil) 9 responds to radio waves in the ~~X~~ Z direction.

The transponder 12 may be provided with a magnetic recording layer, such as a magnetic stripe 13, at the surface, and the antenna 14 in accordance with the present invention as shown in FIGs. 5A and 5B. The transponder can be used in both the contact and non-contact states. Any printing may be applied on the surface without magnetic recording for visual judgement. Any embossment can be formed at the sections other than the antenna, circuit and magnetic recording layer for clearer printing and improving the durability against rewrite and wear. The transponder 12 has a circuit chip 16.

An antenna for a transponder in accordance with a third embodiment will now be explained.

Examples of soft magnetic materials used for the flake of the antenna for the transponder in accordance with a third embodiment of the present invention include pure iron, silicon steel, permalloys (Fe-Ni alloy), iron/cobalt amorphous alloys, and in particular, cobalt amorphous alloys (Co-Fe-Ni-B-Si). Amorphous alloys have excellent high-frequency characteristics, and are readily formed to flakes by striking to quench the molten drops from the molten alloy flow on a copper surface cooled with water.

The thickness of the flake is preferably 30 μm or less, and more preferably 10 μm or less, to prevent the effect of eddy current. A larger flake diameter can increase the permeability of the composite material and decrease the magnetic core size. However, an excessively large diameter of the flake barely homogenizes the magnetic core material. Accordingly, flake diameter ranges 50 to 2,000 μm, and preferably 100 to 1,000 μm.

Examples of synthetic resins include ~~thermoses~~ thermoset resins, e.g. epoxy resins, phenol resins, urea resins, unsaturated polyester resins, diacrylphthalate resins, melamine resins, silicone resins, and polyurethane resins; and thermoplastic resins, e.g. polyethylene resins, polypropylene resins, vinyl chloride resins, fluoroplastics, methacrylate resins, polystyrene resins, AS resins, ABS resins, ABA resins, polycarbonate resins, polyacetal resins, and polyimide resins.

The flexibility of the composite material increases and the shaping characteristics improves with the increased synthetic resin content in the composite material. When the resin content is too small, the strength of the composite material decreases. On the other hand, an excessive synthetic resin content causes a decrease in permeability. Accordingly, the preferable amount of the synthetic resin is 3 to 50 ~~weight%~~ % by weight, and more preferably 10 to 40 ~~weight%~~ % by weight of the composite material.

Usable molding methods include injection molding, compression molding, rolling, and doctor blade shaping. A composite material having excellent magnetic characteristics can be obtained by compression molding, rolling or doctor blade shaping, since the flake plane is oriented to the plane of the composite material. The size suitable to carry is 0.3 to 2 mm in thickness, 100 mm or less in width and length, and in particular, 0.3 to 1 mm in thickness, 10 to 25 mm in width, and 60 to 80 mm in length.

When the conductor forming the coil is too thick, the antenna becomes too thick, whereas the excessively thin conductor causes an increase in resistance. Thus, the diameter of the conductor preferably ranges 100 to 200 μm.

It is preferred that the coil is wound perpendicular to the longer side of the antenna, in other words, the coil axis is parallel to the longer side.

The antenna for the transponder in accordance with the present invention exhibits excellent effects in that the antenna is thin and flexible, the loss is low at a high frequency over 100 kHz, and the antenna is less affected by a coin or an aluminum foil package.

A transponder using an antenna in accordance with a fourth embodiment of the present invention will now be explained.

In this transponder, two plate antennas in accordance with the third embodiment are placed perpendicular to each other, and an air-core antenna composed of a spirally wound conductor is placed, similar to the second embodiment set forth above, because the direction of the transponder antenna is not always oriented in the direction of the magnetic flux of the reading machine when the transponder in a pocket passes through an automated wicket. As shown in FIGs. 7A and 7B, the two thin plate antennas 26, 27 in accordance with the present invention are provided in the plate transponder 28 so as to cross the axes of the coils or antennas of each other, and the air-core antenna composed of the air-core spiral coil 29 is provided in the plate transponder 28 so that the axis of the antenna is perpendicular to the plate of the transponder. Axes of the antennas 26, 27 and of the antenna composed of the coil 29 are preferably directed to three directions perpendicular to each other. These antennas have chip circuits 31.

When the transponder is used as an ID card or an automated wicket in the pocket, the correlation between the direction of the interrogator antenna and the direction of the transponder is not fixed. Thus, the transponder must respond to radio waves from all the directions. A transponder, which has two plate antennas crossing each other, can respond to the direction parallel to the plate, but cannot respond to the direction perpendicular to the plate. On the other

hand, the plate transponder shown in FIGs. 7A and 7B can respond to waves from all the directions, regardless the direction of the transponder; the antenna 27 responds to radio waves in the X direction, the antenna 26 responds to radio waves in the Y direction, and the air-core antenna (coil) 29 responds to radio waves in the ~~X~~ Z direction.

Experiment 1

A sheet composed of Allied Signal METAGLAS 2714A having a width of 50 mm and a thickness 25 μm was used as a magnetic core material. The sheet was cut into a size shown in Table 1, was heated at 250°C for 10 min. in air, and quenched. A magnetic core was produced by layering a few sheets so as to reach the thickness shown in Table 1. An insulation conductor having a diameter of 0.15 mm was wound up on the magnetic core so that the L of the coil is approximately 3 mH. The conductor was wound in the direction parallel to the longer side of the magnetic core in Examples, and in the direction parallel to the shorter side of the magnetic core in Comparative Examples.

The resistance of each antenna due to the magnetic core was evaluated by the following equation from the resistance R obtained from Yokogawa-Hewlett-Packard LCR meter 4284A:

$$R_1 = R - R_2$$

wherein R_1 represents a resistance due to the magnetic core, R represents an observed resistance, and R_2 represents a direct current resistance of the coil.

Results are shown in Table 1. Table 1 demonstrates that the resistance significantly decreases by winding the coil in the direction parallel to the longer side of the magnetic core.

As shown in FIGs. 6A and 6B, the magnetic core size perpendicular to coil axis represents A, the magnetic core size parallel to coil axis represents B,and the magnetic core size perpendicular to the plane AB represents C.

Experiment 2

A sheet composed of Allied Signal METAGLAS 2714A having a width of 50 mm and a thickness 25 μm was cut into 50 mm by 25 mm. Four corners of the cut sheet in Example A were cut as shown in FIG. 3A (a=6 mm). Four corners of the cut sheet in Example B were rounded as shown in FIG. 3B so as to form arcs (R=6 mm). Each corner in Example C was maintained to right angle. Sheets were heated at 250°C for 10 min. in air, and quenched. A magnetic core of each Example was produced by layering three sheets. An insulation conductor having a diameter of 0.15 mm was wound up twice by each 85 turns in the direction parallel to the longer side of the magnetic core to form an antenna. The direct current resistance of the coil was 20.4Ω.

The resistance of each antenna due to the magnetic core was evaluated similar to Experiment 1. Results are shown in Table 2. Table 2 demonstrates that the resistance significantly decreases by eliminating the corners of the magnetic core.

Experiments 3

(Example)

A sheet composed of Allied Signal METAGLAS 2714A having a width of 50 mm and a thickness 0.025 mm was cut into 50 mm by 25 mm, heated at 250°C for 10 min. in air, and

quenched. A magnetic core was produced by layering three sheets. An insulation conductor having a diameter of 0.16 mm was wound up by 180 turns in the direction parallel to the longer side of the magnetic core.

(Comparative Example)

On the other hand, an antenna composed of an air-core coil of which a conductor having a diameter of 0.016 mm was wound to 400 turns.

(Measurement)

The resistance of the magnetic core of each sample, of which a 10-yen coin was placed in the coil center as shown in FIG. 2B, was measured similar to Experiments 1 and 2. Results are shown in Table 3. Table 3 demonstrates that the antenna of the Example exhibits a smaller resistance in a practical frequency region as a transponder of 40 to 200 kHz.

<u>Experiment 4</u>

(Examples)

<u>No. 1</u>

A magnetic core material was prepared by mixing Co-type amorphous metal flakes having an average thickness of 5 μm and an average diameter of 500 μm with an epoxy resin in an amount of 10% (the rate of the resin to the total of the flake and resin) and by compression-molding at 160 °C and 200 kg/cm^2. The magnetic core material was cut into cut sheets having a thickness of 0.6 mm, a width of 25 mm, and a length of 80 mm. A conductor having a diameter of 0.15 mm was wound in the direction parallel to the cut sheet so that L is 3 mH.

No. 2

A magnetic core material was prepared by mixing Co-type amorphous metal flakes having an average thickness of 5 μm and an average diameter of 500 μm with an epoxy resin in an amount of 20% (the rate of the resin to the total of the flake and resin) and by compression-molding at 160 °C and 200 kg/cm^2. The magnetic core material was cut into cut sheets having a thickness of 0.6 mm, a width of 25 mm, and a length of 80 mm. A conductor having a diameter of 0.15 mm was wound in the direction parallel to the cut sheet so that L is 3 mH.

No. 3

A magnetic core material was prepared by mixing Co-type amorphous metal flakes having an average thickness of 5 μm and an average diameter of 500 μm with an epoxy resin in an amount of 30% (the rate of the resin to the total of the flake and resin) and by compression-molding at 160 °C and 200 kg/cm^2. The magnetic core material was cut into cut sheets having a thickness of 0.6 mm, a width of 25 mm, and a length of 80 mm. A conductor having a diameter of 0.15 mm was wound in the direction parallel to the cut sheet so that L is 3 mH.

No. 4

A magnetic core material was prepared by mixing Co-type amorphous metal flakes having an average thickness of 5 μm and an average diameter of 500 μm with an epoxy resin in an amount of 40% (the rate of the resin to the total of the flake and resin) and by compression-molding at 160 °C and 200 kg/cm^2. The magnetic core material was cut into cut sheets having a thickness of 0.6 mm, a width of 25 mm, and a length of 80 mm. A conductor

having a diameter of 0.15 mm was wound in the direction parallel to the cut sheet so that L is 3 mH.

No. 5

A magnetic core material was prepared by mixing Co-type amorphous metal flakes having an average thickness of 5 μm and an average diameter of 300 μm with an epoxy resin in an amount of 20% (the rate of the resin to the total of the flake and resin) and by compression-molding at 160 °C and 200 kg/cm^2. The magnetic core material was cut into cut sheets having a thickness of 0.6 mm, a width of 25 mm, and a length of 80 mm. A conductor having a diameter of 0.15 mm was wound in the direction parallel to the cut sheet so that L is 3 mH.

No. 6

A magnetic core material was prepared by mixing Co-type amorphous metal flakes having an average thickness of 10 μm and an average diameter of 500 μm with an epoxy resin in an amount of 20% (the rate of the resin to the total of the flake and resin) and by compression-molding at 160 °C and 200 kg/cm^2. The magnetic core material was cut into cut sheets having a thickness of 0.6 mm, a width of 25mm, and a length of 80 mm. A conductor having a diameter of 0.15 mm was wound in the direction parallel to the cut sheet so that L is 3 mH.

No. 7

A magnetic core material was prepared by mixing Co-type amorphous metal flakes having an average thickness of 5 μm and an average diameter of 500 μm with a mixture of a urethane resin and an epoxy resin in an amount of 20% (the rate of the resin mixture to the total

of the flake and resin mixture) and by compression-molding at 160°C and 200 kg/cm^2, The magnetic core material was cut into cut sheets having a thickness of 0.6 mm, a width of 25 mm, and a length of 80 mm. A conductor having a diameter of 0.15 mm was wound in a direction parallel to the cut sheet so that L is 3 mH.

(Comparative Examples)

No. 1

A magnetic core material was prepared by cutting Allied Chemical METAGLAS 2714A into a rectangular pieces having a width of 25 mm and a length of 50 mm. A magnetic core having a thickness of 0.3 mm was produced by layering 12 pieces. A conductor having a diameter of 0.15 mm was wound in the direction parallel to the cut sheet so that L is 3 mH.

(Measurement)

The resistance R (loss) of each coil was measured with a Yokogawa-Hewlett-Packard LCR meter. Results are shown in Table 4.

Table 4 demonstrates that the antenna in accordance with the present invention exhibits a small loss in a high frequency region over 100 kHz.

(Table 1)

	Magnetic Core Size				Resistance due to Magnetic Core R_1 (Ω)								
	A (mm)	B (mm)	C (μ)	B/A	30 kHz	40 kHz	50 kHz	60 kHz	80 kHz	100 kHz	120 kHz	150 kHz	250 kHz
Examples	50	15	300	0.3	1.5	2.1	3.8	5.9	10.3	16.5	24.4	40.8	84.3
	50	20	300	0.4	2.3	4.1	5.8	8.5	14.7	23.0	26.4	48.2	98.8
	50	25	75	0.5	2.3	4.3	6.7	9.7	17.2	26.0	38.9	60.8	108
	50	25	150	0.5	2.4	4.8	7.3	10.1	17.5	26.8	37.8	56.2	106
	50	25	300	0.5	2.7	4.7	6.6	9.2	15.8	24.1	33.8	52.3	96.3
	50	25	600	0.5	2.7	4.8	6.4	8.6	14.9	23.5	32.4	49.6	92.3
	50	35	300	0.7	5.9	10.4	16	23.3	42.8	70.9	114	224	840
	50	50	300	1.0	9.9	17.7	28.2	41.6	77.5	134	224	480	2500
Comparative Examples	50	75	300	1.5	10.8	25.1	38.0	80.7	103	162	281	816	4250
	50	100	300	2.0	12.7	28.8	48.9	72.5	115	194	335	910	5650
	50	200	300	4.0	16.6	30.1	59.7	94.3	140	253	440	1030	7400

Remarks
A: Magnetic core size perpendicular to colil axis
B: Magnetic core size parallel to coil axis
C: Thickness

(Table 2)

Frequency (kHz)	Example A Core with Cut Corner (Ω)	Example B Core with Rounded Corner (Ω)	Example C Core without Corner Treatment (Ω)
30	2.1	2.2	2.7
40	3.7	3.8	4.4
50	3.5	3.7	4.8
60	5.7	6.0	7.8
80	13.9	14.5	17.6
100	23.7	24.7	29.4
120	37.7	39.2	46.6
150	54.1	56	65.8
200	108.6	112.3	134.1

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(Table 3)

Frequency (kHz)	Example Coil with Core Core Diameter 0.16 mm Number of Turns 180 (Ω)	Comparative Example Air-core Coil Conductor Diameter 0.16 mm Number of Turns 400 (Ω)
30	6.2	20.0
40	8.8	23.3
50	11.6	26.4
60	14.8	29.5
80	21.7	35.3
100	29.9	41.2
120	39.0	47.1
150	55.6	56.3
200	70.0	73.1

(Table 4)

Frequency kHz	Resiostance R (Ω)							
	Example No. 1	Example No. 2	Example No. 3	Example No. 4	Example No. 5	Example No. 6	Example No. 7	Comp. Ex. No. 1
50	29.3	30.8	31.3	32.7	31.0	30.8	30.7	23.7
80	29.5	31.0	31.8	32.3	31.4	31.6	31.4	26.1
100	29.8	31.3	32.8	33.1	31.9	30.7	31.3	29.4
120	33.4	33.4	33.5	33.4	33.3	33.7	33.2	46.6
150	38.1	36.6	38.9	38.6	39.1	39.4	38.9	65.8
200	76.6	54.3	48.8	43.5	54.9	57.0	53.6	134.1
250	125.0	73.0	85.7	61.6	73.8	80.3	71.9	201.2
300	193.3	110.1	106.8	80.9	110.7	132.1	113.1	301.7
400	395.0	271.6	121.5	87.0	274.1	353.1	271.0	452.6
500	1243.3	914.3	583.9	413.6	913.5	1280.0	936.4	1678.9